Final Report

Analyses of a Fuels Treatment in the Northern Boreal Forest

Technical Fire Management – 15
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Contents

Executive Summary

Fuel breaks and fuel treatments are receiving a tremendous amount of attention in the aftermath of the 2000 wildfire season. Defensible, defendable and survivable space have become common terms when addressing fuel treatments in the wildland urban interface community. To meet the demands of these definitions, fuels management techniques in the Wildland Urban Interface often incorporate thinning treatments with various slash disposal treatments.

When managing forested areas by fuels reduction, one objective of these treatments often involves the reduction of fire behavior characteristics. One of the fire behavior characteristics that most discussions of fire behavior in the wildland urban interface ultimately lead to is the determination of the potential for crown fire activity. Crown fires are a concern given the difficulty of suppression, the damage they inflict on resources and the hazard exposed to the fire fighter. Fire managers must consider the potential reduction of fire behavior when developing parameters for fuel breaks.

The majority of crown fires in the black spruce fuel type are dependent active or passive crown fires. Fire in the boreal forest type cannot be sustained without the support of the surface fire. This paper will discuss a process to measure the threshold change for crown fire initiation after a fuels treatment. Using current fire behavior prediction programs, reductions were seen in fireline intensity, associated flame length, and crown fraction burned in the treated area applying one set of weather conditions. Recommendations as to future research needs are included in the discussion and conclusion.

This paper is broken into 2 sections.
The first section will analyze forest plot data to determine the change in stem density and live crown mass utilizing plot data. Additionally, this section will look at developing this data set to assist in analyzing the fire behavior characteristics of the treatment area compared to the non-treatment area of the Shannon Park fuel treatment area.

The second section uses the live crown mass, height to live crown base and crown bulk density along with well-established procedures for predicting fire behavior, specifically examining crown fire initiation thresholds. This data will be used to compare the crown fire characteristics of the 1999 fire (non-treatment) and the potential crown fire characteristics of the treatment area.

The process outlined will aid fire mangers in quantifying crown fire characteristics in existing fuel profiles as well as assist in the design of future fuels treatment projects.

Introduction

In June of 1999 the Shannon Park fire occurred on Military lands adjacent to a Fairbanks Alaska residential community. Given the active crown fire and the proximity to the residential area, the suppression response was prioritized. Ten structure engines, 9 smokejumpers, and 6 helitack, and one Type 2 crew responded. Four loads of fire retardant and numerous water bucket drops were essential in containing this wildland urban interface fire incident to 12 acres.

Crown fires generally represent a level of fire behavior that normally preclude direct suppression actions. In the Shannon Park fire, if not for the quick response and availability of personnel, fire retardant and helicopter water bucket drops, the outcome may have been devastating to the residents of the subdivision. (Appendix B 2)

Fire managers are tasked with reducing this crown fire potential. One of the factors in assessing the efficacy of a fuels reduction treatment is to look at the transition from a surface fire to a crown fire. In a description by Quintilio[1] it was stated the stand density and height of the aerial fuels seemed to affect the crown involvement significantly under moderate and high fire danger conditions. Statements such as these give credence to hazard fuel reduction projects.

Given the high flammability of the black spruce fuel type, the high potential for human caused ignition near residential areas and high values at risk, this area was prioritized for hazardous fuel reduction. Many fuel reduction options were addressed and researched. After a public meeting process and community interaction, the recommended and elected treatment was hand thinning followed by piling and burning. Given this area was in the urban interface, this treatment provided the most effective method for reduction in fuels.[2] This treatment was selected not only to reduce the crown fire potential but also to improve accessibility for a defendable space as well as address the aesthetic appearance criteria that were developed through the public process. The fuel treatment specifications (spacing of the trees and fuel break width) were derived from the corporate knowledge of fire specialists. Other factors considered in the development of the specifications were the appearance of the forested area, budget allocations, and available resources.

The purpose of this report is to fulfill the final requirements of the Technical Fire Management program as well as describe a process for determining the effectiveness of the Shannon Park Hazardous Fuel Reduction Project in terms of crown fire initiation.

The data and information used in this project was acquired through the following methods:

Primary plot data was collected from the United States Army Alaska (USARAK) Natural Resources Department.

Various personal contacts were also made with professional foresters at the University of Alaska, Alaska Fire Service, Tanana Chiefs Conference and USARAK Natural Resources Department. Marty Alexander, Fire Research Officer of the Canadian Forestry Service was extremely informative in this process.
Pacific Northwest Research Station (PNW) experts were contacted on the Photo series application process.
Several fire managers were consulted on practical fire behavior experience in the validation of theoretical fire behavior prediction systems.
The Alaska Interagency Coordination Center supplied historical weather data for the Shannon Park fire of 1999 from the Western Regional Climate Center database.
To develop the null hypothesis for this project as well as provide an overall perspective on fuels treatments, I acknowledge *the Final Report: Effects of Fuels Treatment on Wildfire Severity* submitted to the Joint Fire Science Program Governing Board March 2002 by principal investigators Dr. Phil Omi and Erik Martinson.

[1] Quintilio, D.; Fahnestock, G.R.; Dube D.E. 1977.
[2] Omi, P. N., and K. D. Kalabokidis. 1998. P.34.

The term “fuel break” that will be used throughout this report is best described as “a strategically located wide block or strip on which a cover of dense, heavy, or flammable vegetation has been permanently changed to one of lower fuel volume or reduced flammability”. [3] These areas have been hand manipulated for the purpose of reducing fuels to lessen the spread of wildland fires. The fuel break is created by “altering surface fuels, increasing the height to the base of the live crown, and opening the canopy by removing trees”. [4]

Management Direction

Given the rising population and expansion of urban residents into the wildland, conflicts between the two are inevitable. Residential development in areas with fire-adapted vegetation has created an extensive wildland-urban interface, which involve the most important risks associated with fire. These risks are those to life and structures.[5] Management has recognized the situation and has called upon the fire management communities to take the lead in providing solutions to the wildland urban communities at risk from wildfire.

On August 8, 2000, President Clinton asked Secretaries Babbitt and Glickman to prepare a report that recommends how best to respond to this year's severe fires, reduce the impacts of these wildland fires on rural communities, and ensure sufficient firefighting resources in the future.
The President also asked for short-term actions that Federal agencies, in cooperation with States, local communities and Tribes, can take to reduce immediate hazards to communities in the wildland-urban interface and to ensure that land managers and firefighting personnel are prepared for extreme fire conditions in the future.[6]

This management direction provides opportunities for individual communities in Alaska as well as communities in all states to assess and implement hazard fuels reduction projects to reduce potential for wildfire encroachment. Fuel treatments such as described in this paper are one alternative that may meet this goal.

Problem Statement

As the urban population moves further into fire dependent landscapes, fuels treatment alternatives need to address lessening the crown fire potential. Since the use of fire to treat the adjacent lands is often an undesirable alternative, the question then arises as to how to effectively treat the landscape to reduce to crown fire initiation potential. Fuel treatments are thought to aid in the successful application of aerial and ground fire suppression resources. But, the question arises as to the overall efficacy of a fuel treatment to include the potential fire it will sustain. At present the Shannon Park Fuel Reduction Project has not been researched as to its efficacy in terms of fire behavior characteristics.

Goal Statement

The goal of this project is to quantitatively determine the efficacy of the Shannon Park fuel reduction treatment in terms of crown fire initiation thresholds.

This report will examine the crown fire potential change in a site-specific fuels reduction project. At the conclusion of this study, a determination will be made as to the efficiency of one fuels reduction treatment area in terms of crown fire initiation.

[3] Green, L.R. 1977.
[4] Agee, J. K.; Bahro, Berni, Finney, Mark A.; Omi, Phillip N.; Sapsis, David B.; Skinner, Carl N.; van Wagtendonk, Jan W.; and Weatherspoon, C. Phillip. 1998. P. 2.
[5] Fried, J.S.; Winter, G.J.; and Gilless, J. K. 1999. P.9.
[6] Managing the Impact of Wildfires on Communities and the Environment; A Report to the President in Response to the Wildfires of 2000; September 8, 2000.

Success in achieving this goal will be measured by the completion of the following 3 *objectives* and test the null hypothesis in support of the research goal.

- Analyze and compare variable plot cruise data to determine fuel load characteristics of the treatment and non-treatment areas.
- Compare fire behavior characteristics associated with the treatment area and non-treatment area.
- Develop a method for assessing the efficacy of this fuel treatment.

The primary null hypothesis this paper analyzes is that this specific fuel treatment did not reduce the crown fire initiation potential. This characteristic can be described in analyzing and modeling fireline intensity as it relates to flame length. This process will be modeled using actual plot data as input into NEXUS, BEHAVE, and FBP97. The outputs of each model will be discussed as a process to analyze the potential change in fire behavior characteristics namely fire intensity, flame length and crown fraction burned.

Therefore, the null hypothesis tested is as follows:

H_{01}: The Shannon Park fuel treatment did not reduce the modeled crown fire characteristics.

H_{01a}: The Shannon Park fuel treatment did not reduce the potential crown fraction burned.

H_{01a}: The Shannon Park fuel treatment did not reduce the potential fire intensity (flame length).

Background and Site Description

The present study is in the black spruce fuel type of the Northern Boreal Forest. This site is located on Fort Wainwright Army Base Lands. (Appendix A1, A3) Adjacent to this military training area is the Fairbanks residential subdivision of Shannon Park. Structures and other personal miscellaneous items are common within feet of the military forested area.

The vegetation in this area is dominated by black spruce. (Appendix A 2) The black spruce species characteristics are especially prone to crown fires. The layered lower branches of the black spruce are commonly buried in the moss layer. This feature provides a continuous fuel source from the ground to the crowns of the trees. In addition to this layering effect, the shallow root system, thin bark tendencies, and lichen component on the lower branches make the black spruce especially prone to dependent crown fire.[7] The Canadian Forest Fire Prediction System (Appendix J) catalogs this fuel type as the C2 Boreal Spruce. This fuel type is described as a pure, moderately well stocked black spruce stands on lowland and upland sites. Low to moderate volumes of down woody material is present. Labrador tea is often the major shrub component. A carpet of feather mosses and/or ground dwelling lichens dominate the forest floor. Sphagnum mosses may occasionally be present. But they are of little hindrance to surface fire spread.[8] (Appendix B 1)

Further description of this area can be related to the PNW photo series.[9] The *Stereo Photo Series for Quantifying Natural Fuels* has been produced as a tool for land managers to assess the landscape as well as a quick field guide for predicting fuel consumption, smoke production, fire behavior, and fire effects during wildfire and prescribed fire. The BS10 black spruce best represents the treatment area of the Shannon Park area. (Appendix G).

[7] Vierick, L.A.: Schandelmeier, L.A. 1980.
[8] Forestry Canada Fire Danger Group 1992.
[9] Ottmar, Roger D.; Vihnanek, Robert E. 1998.

A fuel break 1.2 miles in length and averaging 120 feet in width was constructed on Military lands directly adjacent to the private property. The treatment selected was thinning with stem removal by means of hand cutting, piling and burning. Trees were thinned at an average 8 x 8 spacing and pruning the leave trees lower branches an average of 5.4 feet from the ground surface. Trees were felled by chain saw and logs were bucked to a 6-inch diameter. Bucking was done directly after felling and all felled stems were hand carried and piled for use as firewood. All other materials were piled in the unit for burning. Seventy percent of the piles were burned 2 months post treatment while the remainder was completed March 2001.
In August 2000 a variable plot cruise inventory was completed. (Appendices B 4 and B5)

The inventory of fuels was based on the point sampling method as described in the McGraw-Hill Series in Forest Resources.[10] A variable plot cruise transect was completed with 12 plots in both treatment and non-treatment areas. Three distinct forest types were identified in the total length of the fuel break. (Appendix A 3) The data used in this assessment contains the timber type located in the center portion of the fuel break. This area was chosen for two reasons: 1) The data between the non-treatment and treatment were representative of stand composition conditions before treatment and 2) the example fire of 1999 occurred in the non-treatment area.

Fire Characteristics Overview

The basic features of a wildfire are 1) it spreads 2) it consumes fuel and 3) it produces heat energy. The behavior of fire once ignition has occurred is a result of a complex relationship between the mass (fuel) and the energy generated by this relationship. Given this complex relationship, the physical qualities of fire behavior are highly variable. Although this process maybe difficult to describe and predict with preciseness fire researchers, practitioners, and managers have provided prediction equations, models, and tools to assist in describing actual and potential fire behavior characteristics.

Fire Intensity

One method of describing a fire is by describing energy output. George M. Byram defined fire intensity as the heat release per unit of time per length of the fire front. This can be described as the amount of energy that is generated in a strip about one meter in width at the flame front. Fire line intensity cannot be measured in the field but can be derived by the following equation.

Equation 1) $I_s = HwR$

I_s is the actual calculated surface intensity expressed as kw/m.
H is the net heat of the combustion process expressed in kj/kg.
W is the quantity of fuel consumed in the active flaming front expressed in kg/m^2.
R is the linear rate of spread expressed as m/min.

The "H" in this equation is generally considered a constant at 18000 kj/kg for practical purpose.

The "w" in the fire intensity equation refers to the fuel consumed in the active flame front. The amount of fuel available for combustion especially in the organic surface component of the forest floor is primarily a function of moisture content.

The "R" represents the actual rate of spread that can be measured on site. Solid approximations can be derived from practical situations as well as through the use of prediction models.

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[10] All inventory methods were established by USARAK Department of Natural Resources Forestry using Avery, T.E.; Burkhart H.E.; 1996.

Flame Length

Flame length can also be used to approximate the fire intensity. Given flame length can be visually measured on site, this is often a practical method of approximation. Byram (1959) derived the following equation for surface fires.

Equation 2) $L = 0.0775\ (I)^{0.46}$

L is the flame length expressed in meters.
I is the frontal intensity kw/m.

Flame length is defined as the distance between the flame tip and the mid-point of the active combustion zone in a spreading fire taking into account both vertical and horizontal measurements. Flame length is often confused with flame height. Flame height is the maximum vertical extension. Only when there is no wind present are the flame length and the flame height equal. This relationship between flame length and flame height can be shown through this geometric equation.

Equation 3) $L = hf / \sin A$

L is the flame length expressed in meters.
hf is the flame height (m).

A is the flame angle in degrees.

Appendix D) Figure 1 graphically shows this relationship between the amount of available fuel and rate of spread to fire intensity. Figure 2 then shows the relationship of flame length and the surface fire intensity.

Crown fire Initiation

Crown fire initiation is an important factor when discussing fuel break parameters. According to Van Wagner[11], to determine whether a surface fire will ignite the crown of a coniferous forest the following criteria are vital.

Initial surface fire intensity
Crown foliar moisture content
Height of crown layer above ground

Van Wagner (1977) theorized that vertical spread would occur when the surface fire intensity attains or exceeds a certain critical surface intensity for crown combustion. Foliar moisture content plays a critical role in assessing the crown fire potential in a coniferous forest. The overall moisture content is lowest in late May rising early June and then levels off mid July. C. Van Wagner suggests that it is this late May- early June time period that provides the time in which there is the most potential for crown fire.

Equation 4) $I_o = (.01 * LCBH\ (460 + 26\ FMC))^{1.5}$

I_o is the critical surface fire intensity.
LCBH is the live crown base height expressed in m or ft
FMC is the foliar moisture content (foliage/needles) expressed in percent.

The intensity number generated by this equation is the value at which crown fire would be initiated. In other words this equation determines the likelihood of a surface fire spreading to the crown. Crowning is not likely if the critical intensity is not met by the actual fire surface intensity.

Once crown fire activity has been initiated the next parameter to address is whether the crown fire will spread across the terrain. To determine whether the flame will be sustained within the crown layer, Van Wagner added the following two criteria.

Bulk density of foliage within crown layer
Rate of fire spread after crowning

The following equation assesses the relationship of crown bulk density and the rate of spread to determine this threshold.

Equation 5) $R_o = 3.0/CBD$

R_o is the critical rate of spread expressed in m/min.
CBD crown bulk density is expressed in kg/m^3

Appendix E) Figure 3 graphically shows the critical intensity as it relates to the live crown base height and foliar moisture content. Figure 4 then relates the flame length relationship using Equation 2. Figure 5 graphically shows the relationship of the crown bulk density to the critical rate of spread for an active crown fire.

Fire Types and Descriptors

There are three types of fire recognized in forest fires[12]: ground, surface, and crown. Factors in defining these types rely on what fuel layer is involved in the combustion process. This transition phase from a surface to a crown fire is significant in the world of fire behavior. Fires involving the crown layer offer fire behavior that is difficult for firefighting forces to control. It is the transition to the crown fire that will be important in assessing the effectiveness of this fuel treatment.

Crown fires are classified into one three types: passive, active, or independent according to the degree of dependence on the surface fire phase. The passive or active fire addressed in the black spruce fuel type is dependent. Specifically, the crown fire is dependant on the fire sustained by the surface fire.

The passive crown fire may occasionally torch trees as individuals. Passive has often also been described as intermittent crown fire activity. Generally, the surface rate of spread is the controlling factor. The crowning activity often reinforces the spread rate of the fire thus increasing the rate of fire spread.

The active crown fire advances with a well-defined wall of flame extending from the ground surface to the crown fuel layer. The surface fire and the crown fire are spreading at approximately the same rate. The crown fire is dependent on the surface fire to maintain its forward momentum.

The independent crown fire advances in the crown fuel layer only. The surface fire lags some distance behind the leading edge of the crowning phase. This is where fire advances through the crown fuel layer independent of the surface fire.

In the Alaska boreal forest, fire in the crown is dependant on the surface fire activity. Therefore the transition to crown fire is an important characteristic to examine.

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[11] Van Wagner, C.E. 1977.
[12] Alexander, Martin E.1987; Van Wagner. 1977.

Van Wagner (1983) provides a basic classification of fire intensities to further relate fire intensities to the type of fire behavior associated:

Smoldering fire in deep organic layers	< 10 kw/m
Surface backfires	100 to 800 kw/m
Surface head fires	200 to 15,000 kw/m
Crown fires (single front)	8,000 to 40,000 kw/m
High intensity spotting fires	up to 150,000 kw/m

Alexander (1988) provides a Forest Fire type summary key that is helpful in further describing the relationship of surface fire intensity to crown fire activity.

I. Surface fire intensity (I_s) is predicted to be less than 10 kw/m.

A. Single ignition to occur — **Self extinguishing fire; fails to spread**
B. Going Fire — **Ground or subsurface fire**

II. Surface fire intensity (I_s) is predicted to be greater than 10 kw/m but less or nearly equal to the Critical Surface Intensity for Crown Combustion (I_o).

A. I_s is substantially less than I_o — **Surface fire**

B. I_s is nearly equal to I_o — **Developing passive crown fire**

III. Surface Fire Intensity (I_s) is predicted to be equal to or greater than the Critical Surface Intensity for Crown Combustion (I_o).

A. Rate of fire spread (R) is predicted to be less than or nearly equal to the Critical Minimum Spread Rate for Active Crown Fire (R_o).

1. R is substantially less than R_o — **Passive crown fire**

2. R is nearly equal to R_o — **Developing active crown fire**

B. Rate of fire spread (R) is predicted to be equal to or greater than the Critical Minimum Spread Rate for Active Crown fire (R_o).

1. Forward heat transfer through the crown fuel layer relies upon surface fire phase

Active crown fire

2. Energy requirements for the continued propagation through the crown fuel layer supplied entirely by the crown fire phase — **Independent crown fire**

Shannon Park Example

By manipulating the stem density, ladder fuels and the crown to base height in the treatment area, theoretically the potential for crown fire initiation is lessened. To test this concept, the results of the variable plot cruise data for the treatment area were used to calculate the fuel break crown fire parameters. Using the Van Wagner's crown fire theory equations, actual historic weather inputs, and stand characteristics, crown fire initiation can be calculated. Using the fire parameters of the 1999 Shannon Park fire, the fuel break will be tested for crown fire initiation differences.

Procedures for Analysis

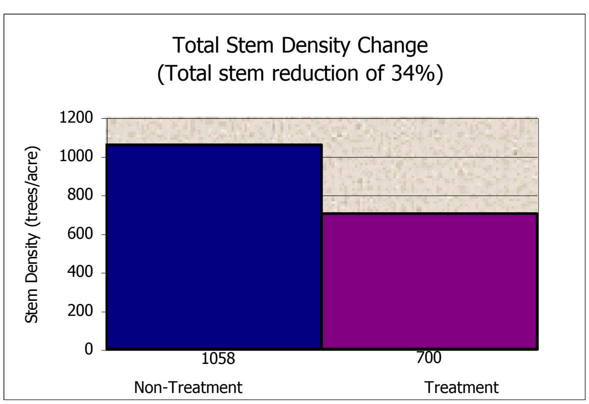
Phase 1 Variable plot data

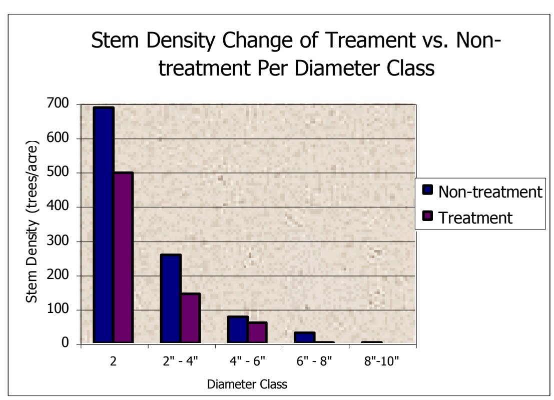
Stem Density

To gather the values needed for these equations, the variable plot data was evaluated. The plot data provided stem density per diameter class, species, basal area, tree height, percent crown cover, and height to live crown. Four spherical crown densiometer readings were read in each cardinal direction at each variable plot center to determine average crown closure. (Appendix E)
These data were used to determine stand density and estimate the average crown closure.

	NT104	T103	% Reduced
Total trees per acre	1058	700	34%
Trees/acre/diameter class			
<2″	688	497	38%
2" - 4"	258	143	44%
4" - 6"	76	47	38%
6" - 8"	29	12	58%
8″ - 10″	7	2	71%
> 10″	1	0	100%
Average Crown Closure	63%	48%	15%

On the average, the thinning reduced tree density from 1058 trees/acre to 700 trees/acre. The total stem density reduction in the treatment was 34%. The average crown closure was reduced by 15%.





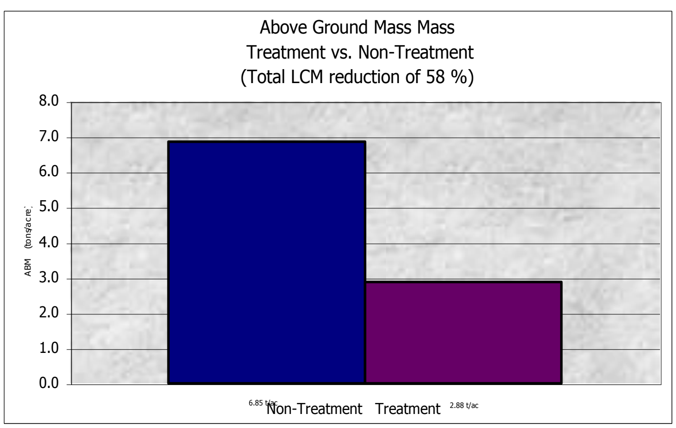
Above Ground Mass

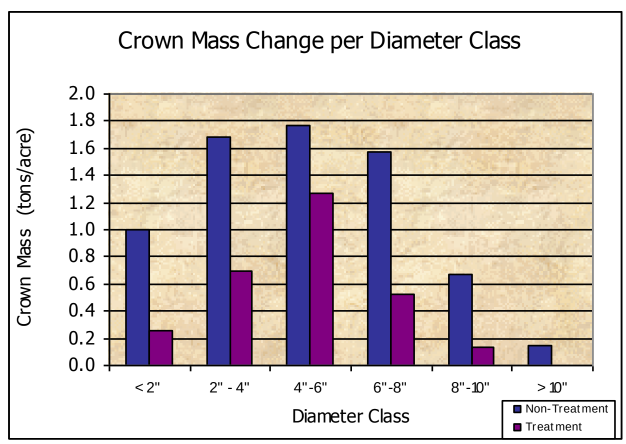
Barney et al.[13] provides a biomass regression equation to determine the total biomass in the upland black spruce. This regression equation is $\log_e y = a + b \log_e x$; where y = mass in grams and x = basal diameter in centimeters. For the upland black spruce foliage regression equation the intercept *a* is 3.63 and slope *b* is 2.54.

Using dbh as the independent variable and the mass as the dependent variable, this equation was accepted as with the following resultant R^2 at .91. The standard error of the estimate in units per gram per tree is 1727.2. This intercept was corrected for logarithmic bias according to the procedures of Baskerville (1972).

Using the Barney biomass regression equation for mass, the non-treatment area contains a total of 6.85 tons per acre. The treatment area foliage total was 2.88 tons per acre.

	NT104	T103	% reduced
Foliage (live crown mass)	6.85	2.88	58%
mass/diameter class			
< 2"	1.00	0.26	74%
2" - 4"	1.68	0.69	59%
4"-6"	1.77	1.27	28%
6"-8"	1.57	0.52	67%
8"-10"	0.67	0.13	81%
> 10"	0.15	0.00	100%





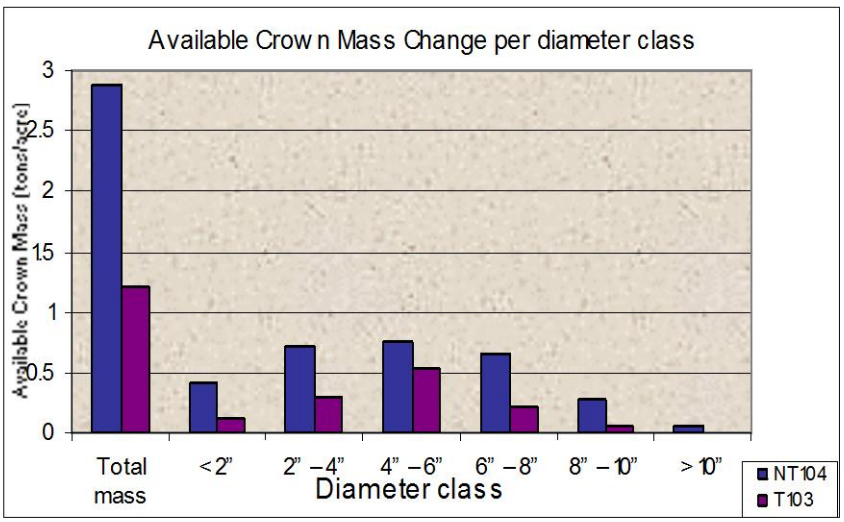
Total *Available* Above Ground Mass or Crown Fuel Load

[13] Barney, R.J.; Van Cleve, K; Schlentner, R. 1977. P. 39.

In the fire world weather plays an important role when assessing "available" fuels for consumption. Seasonally, daily, and hourly the fuels available for combustion will change. In describing basic fire consumption, the crown ignites not only the foliage but also a portion of the smaller diameter woody material in the crown layer. Agee[14] refers to Anderson's (1969) definition of including 50% of the fine branch category in the crown fuel load. It is this class of fuel that is available for consumption and is considered small enough to contribute significant energy during the crown combustion process. Delving deeper into this subject, Barney and Van Cleve[15] state that in the upland site approximately 42% of the black spruce total mass is comprised of the foliage and woody diameter class of ¼ inch (.62 cm) and less.

By multiplying the total above groundmass by 42 %, the total available fuel for consumption is derived.

	NT104	T103	% Reduced
Total mass	2.88	1.21	58%
< 2″	0.42	0.11	73%
2″ – 4″	0.71	0.29	59%
4″ – 6″	0.75	0.54	28%
6″ – 8″	0.66	0.22	66%
8″ – 10″	0.28	0.05	82%
> 10″	0.06	0	100%



The crown mass is 2.88 tons/ acre for the non-treatment while the treatment has been reduced to 1.21 tons to equal a 58% decrease in available fuel. For purpose of calculation in fire behavior modeling, the crown mass tons per acre is also described as the crown fuel load and can be expressed in lbs/ft^2 or kg/m^2 to describe a two-dimensional aspect of the landscape. This conversion is accomplished by multiplying total tons by 2000 (lbs) and dividing by 43560 (ft/acre). In this calculation, the non-treatment crown fuel load of .13 lbs/ft^2 (.65 kg/m^2). The treatment averaged overall with a .08 lbs/ft2 (.38 kg/m^2).
Again, this calculation verifies the overall 58% change in total available fuel in the study area.

Crown Bulk Density

[14] Agee, J. K. 1996.
[15] Barney, R.J.; Van Cleve, K,1973.

Crown bulk density is a measure of weight divided by volume. Necessary inputs to determining the crown bulk density is average tree height, average height to live crown, average crown length and the above ground mass. Assuming that the stand is uniform, the crown bulk density can be determined by dividing the total available crown weight by the average live crown length. Average live crown length is the average tree height minus the average height to live crown base.

The crown bulk density calculated through this process for the non-treatment was .17 kg/m^3. The treatment crown bulk density resulted in .13 kg/m^3.

Summary of the stand descripters for the treatment and non-treatment.

Feature	Non-Treatment	Treatment
Stem density (trees/acre)	1058	700
Tree Spacing (ft)	6 x 6	8 x 8
Tree height (ft)	13.7	12.4
Diameter breast height (in) (cm)	2.3 (5.8)	2.2 (5.6)
Ave. Height to live crown base (ft) (m)	1.5 (.5)	5.4 (2.0)
Live crown length (ft)	12.2	6.98
Above ground mass (total) (t/ac)	6.85	2.88
Available Crown Fuel (42.1% of total) (t/ac)	2.88	1.21
Crown fuel load (lbs/ft^2) (kg/m^2)	.13 (.65)	.06 (.27)
Crown bulk density (lbs/ft^3) (kg/m^3)	.01 (.17)	.01 (.13)

Phase 2 Critical Surface Intensity (CSI) or (I_o)

The second phase of this analysis is to calculate the critical surface fire intensity. To determine $\mathbf{I_o}$ Fireline Intensity for both the non-treatment and treatment areas the following steps are necessary:

1) Gather the historical weather data from the 1999 fire

Weather and environmental data from Shannon Park fire.

Date	Jun-7-99	
Noon air temperature	77.0°F	25 C°
Noon relative humidity	36.0%	
Noon 10 meter wind speed	4.5 mph	7.2 kph
24-hour precipitation	0.0 in	
Time of projection	18:00	
Latitude	64 N	
Longitude	147 E	
Elevation above sea level	427 ft	120 m
Percent ground slope	0.0	
*Fine Fuel Moisture Code FFMC	89	
Duff Moisture Code DMC	65	
Drought Code DC	420	
Initial Spread Index ISI	6.1	
Buildup Index BUI	99.6	
Fire Weather Index FWI	22.4	

* See Appendix J for Canadian Forest Fire Danger Rating System description.

2) Determine foliar moisture content for that date**.**

The foliar moisture content in the coniferous forest varies considerably with the season. For most species the lowest level of moisture occurs in June at this latitude. Using the work of M. Miller (1994)[16] a value of 90% was determined to be strong representative value for this date.

3) Average crown to base height calculation.

[16] NWCG NFES #2394. 1994.

The data average for the live crown base height in the non-treatment was 4.5 feet. (1.4 m). The treatment area was 6 feet (2 m).[17] For purpose of example and also to represent the ladder fuel component and lower branches present in the non-treatment area .5 m will be used and 2.0 m. will be used for the treatment.

[17] This live crown base height value is deceiving when describing the black spruce given the lower branches and layering effect.

4) Critical fire intensity calculation

Using Van Wagner's Critical Fire Intensity Equation (Equation 4) calculate the threshold for crown fire initiation. The associated Critical Flame Length can be assessed using Equation 5.

Non-treatment

$I_o = (.01 *.5 (460+ 26 (90))^{1.5} = 52$ kw/m

$L = 0.0775 (741)^{0.46} = .5$ m

Treatment

$I_o = (.01 * 2.0 (460+ 26 (90))^{1.5} = 419$ kw/m

$L = 0.0775 (2963)^{0.46} = 1.3$ m

Phase 3 Fire behavior calculations

The on-site field reports, fire narrative, and final perimeter of the fire reconstruct the rate of spread at 10 ft/min (3 m/min). The flame lengths were reported at 40 feet in length given the crown fire activity. The crown fraction burn determined from post-fire plots reveal a 80% consumption. (Appendix B 3) This flame and intensity description takes into account the total intensity including the crown fire activity. To separate out the surface intensity, the next phase of this process is to assess the surface intensity associated.

The NEXUS worksheet (Appendix H 1) was used to predict the surface fire intensity and flame length of the Shannon Park fire. The following steps were completed to get the necessary inputs;

1) Calculate the dead fine fuel moisture content for both the treatment and non-treatment using the Moisture Module in Behave. (Appendix H 3)

2) Wind adjustment factors applied:

Recommendation for the non-treatment is .1 (WAF) per Norum (1983).

Recommendation for the treatment area is .2 (WAF)
On site discussions with fire behavior analysts, .2 WAF was the consensus based on the open stand fully sheltered characteristics of the treatment area.

2) Calculate live crown base height
For this purpose of this task, .5 m and 2.0 m for non-treatment and treatment respectively.

Given the presence of the lower branches of the black spruce tree species as well as the ladder fuels of small shrubs and brush, .5 meters was thought to describe the fuel treatment stand accurately.

4) Critical rate of spread

When using the Behave modules in the Alaskan Black Spruce fuel type Norum (1982)[18] suggests NFFL Fuel Model 9 value multiplied by 1.21 for the rate of spread. NFFL Fuel Model 5 is recommended to obtain flame length and fire intensity numbers.

By removing the ladder fuels, the lower limbs of the tree, and reducing stem density the forest stand is then exposed to the wind component. The Moisture module of the Behave system reflects this additional exposure to the fine dead fuel moisture. The non-treatment area fine dead fuel moisture calculates at 9% while in the now more exposed treatment area reveals 8% fine fuel moisture. The wind adjustment factor difference is also reflected in the effective mid-flame speed. With a common 20-foot windspeed of 5 m/hr, the non-treatment effective mid flame windspeed is at .5 m/hr while the treatment is at 1.0 km/hr respectively. It is these two parameters that may or may not decrease the absolute crown fire initiation potential in a fuel treatment.

[18] Norum, R.A. 1982.

Discussion

Comparison Table for Fire behavior characteristic outputs between

NEXUS (BEHAVE) and FBP97

	Non-treatment		Treatment	
	Nexus	FBP97	Nexus	FBP97
Crown fraction	74 %	86 %	50 %	84 %
Fire intensity	2438 kw/m	10055.7 kw/m	1763 kw/m	9217.8 kw/m
Flame length	3.2 m	5.38 m	2.5 m	5.16 m
Rate of spread	.3 m/min	8.5 m/min	.4 m/min	8.5 m/min

For purpose of comparison, the weather and forest conditions were calculated in both the Canadian FBP97 and National Behave (Nexus) modeling programs. These results show the Canadian FBP97 model does not capture the fuels treatment forest stand manipulation[19]. Within the inputs of the C2 Boreal forest fuel model, additional input blocks are available to insert the crown fuel load and live crown to base height. It is believed that the program is not sensitive to these inputs therefore the final fire intensity does not reflect the fuel treatment reduction of available fuel for consumption. This is indicated by the slight difference in the treatment – non-treatment out puts. Although the possibility does exist that the crown fire activity of the treated area will mirror that of the non-treatment as reflected in the FBP97 model outputs, the results of these runs were not applied to the final testing of the hypothesis.

NEXUS Worksheet Results:

	Non-Treatment	**Treatment**
INPUTS		
Fuel moistures (1, 10,100 hr (%))	9, 10, 12	8, 9,12
Crown bulk density	.17	.13
Foliar moisture content (%)	90	90
Crown Base Height (m)	.5	2.0

[19] Per conversation with M. Alexander

Crown fuel load	.65	.27
Wind adjustment factor	.1	.2
OUTPUTS (Surface)		
Final fire type	Passive	Passive
Crown fraction burned	.74	.50
Fire line intensity (kw/m)	2438	1763
Flame length (m)	2.8	2.3
Rate of spread (m/min)	3 (observed)	4 (projected)
Critical Crown Fire Parameters		
Critical Intensity (kw/m)	52	417
Critical Flame Length (m)	.5	1.2
Critical surface rate of spread (m/min)	.8	6.4

The results of the NEXUS run reveal both the non-treatment and treatment will have passive crown fire activity. The Shannon Park Fire burned a total of 12 acres with actual on site measurements of 80 % crown fraction burned. The NEXUS generated crown fraction burned at 74%. This calculation is within an acceptable range therefore will accept the remaining numbers associated with the NEXUS prediction run. The predicted crown fraction burned in the treatment area is at 50 %. The Shannon Park treatment theoretically has reduced the crown fraction burned by 24 %.

The calculated surface intensity of the Shannon Park fire equaled 2438 kw/m thus far exceeding the critical intensity threshold of 52 kw/m. The associated non-treatment flame length of the Shannon Park fire equaled 3.2 m, which is 2.7 meters above the critical threshold of .5 meters. Under these same weather parameters accounting for the wind and the lower fuel moistures, the treatment area fire intensity equals 1763 kw/m, which also exceeds the calculated critical intensity threshold of 417 kw/m. The associated flame length of the calculated fire would be 2.5 meters. Although this flame length does exceed the 1.3 meter critical threshold by 1.2 meters, there is a significant reduction in crown fire activity. This reduction is revealed through the NEXUS modeling program in the crown fraction burned characteristic.

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The rationale for this reduction in the crown fraction burned lies in the critical rate of spread. The critical rate of spread for the non-treatment area is .8 m/min and the actual exhibited rate of spread is 3 m/min. The non-treatment actual rate of spread far exceeds the critical rate of spread thus the ability for the crown fire to sustain consequently 74% crown fraction burned. In comparison, the treatment area critical rate of spread is calculated at 6.4 m/min while the actual projected rate of spread is 4 m/min. Given this difference of 2.4 meters less than the critical rate of spread the crown fraction burned declines to 50 percent.

Conclusion

Theoretically, under these specific environmental conditions of the 1999 Shannon Park fire, the thinning and pruning treatment fire behavior model did show a reduction in the potential for crown fire initiation as related in the crown fraction burned. However, the numbers shown via our current fire behavior prediction models are examples of the current systems lack of sensitivity to evaluate fuel treatments.

The effectiveness of fuelbreaks remains a subject of debate in the fire community. Fuel break parameters and prescriptions will vary with its assigned purpose and also vary given the forest fuel type. In this example, crown fire initiation was discussed. The next step is to widen the scope of this inquiry to include average worst-case fire situations. The Shannon Park fire occurred in mid-June when the temperatures were high and the foliar moisture content was at a seasonal low. Further evaluation to include a wider weather and environmental elements is recommended to establish a true sense of efficacy of a fuel treatment.

The Black Spruce fuel type is exceptionally prone to crown fire given its species characteristics. The thinning and removal of ladder fuels and lower branches treatment in the Shannon Park did show reduction in the crown fire initiation threshold. Agee[20] refers to critical conditions that can be defined in which crown fire spread is unlikely. This theory refers to crown bulk density thresholds that would inhibit active crown fire behavior based on rates of spread in the fuel type of interest. . In fuels types associated with the Pacific Northwest, Agee refers to a .01 kg/m^3 as a threshold. Dr. Agee's process of calculation could be applied to the Northern Boreal Fuel type. This process may be applied to site-specific hazard fuel reduction projects to best determine level of manipulation needed. Further studies and research would have to be accomplished to find the appropriate crown bulk density threshold.

The crown fire potential was not entirely mitigated under the Shannon Park fire prescription but the numbers show the crown fire initiation thresholds were extended. Crown fire behavior represents a problem when addressing fire suppression direct attack. Firefighter exposure to this level of fire is a high-risk situation. Fuel treatments provide opportunities to not only decrease the crown fire potential but can also offer additional success in suppression efforts. By opening the canopy, aerial application of helicopter bucket drops and retardant will have a higher chance of aiding the suppression of surface fire activity in areas that are deemed high values at risk. In analyzing fuel treatment specifications in the wildland urban interface, fire managers may want to consider the crown fire initiation thresholds as well as the potential enhancement in suppression tactic capabilities the treatment may provide.

Suggestions for the Future:
Permanent photo points and monitoring plots are recommended before and after treatment. The variable plot data provided base line measurements and can be completed in a timely manner but the ability to effectively monitor the true effects of the fuel treatment is hampered. Permanent plots would measure the characteristics of the stand with less error and could also monitor the vegetation response, the effect on the permafrost layer, and the effect on growth to the overstory. Fuel treatments such as the Shannon Park project are accomplished nation-wide without a comprehensive understanding as to its long-term effects on the vegetation By establishing a vegetative monitoring system, treatments such as these will be better understood in their entirety

[20] Agee, J.K.1996. P 7.

to include the associated fire behavior characteristics change as well as effects on the forest characteristics.

In answer to the questions and assumptions associated with this project, research is currently underway. A Joint Fire Science Program funded Fuels Demo project[21] will be analyzing this vegetation change given two fuels treatments (8 foot and 10 foot spacing and control plot). Fire behavior modeling will also be included using FARSITE.
Other questions arose as to weather variability (wind, temperature, rh) and associated duff moisture change in the treatment area versus the non-treatment Another University of Alaska Fairbanks research project is being conducted using paired weather stations in the Tanacross Hazard Fuel Reduction Project[22]. Preliminary results from these projects will be available Fall 2002.

International Crown Modeling Experiment is currently analyzing this specific type of paired treatment by implementing fuels treatments and burning the plots under controlled conditions. Future recommendations also include mirroring the Canadian efforts in analyzing fuel treatments such as the Shannon Park. By executing field experiments to include burning can only enhance our understanding of the true effects of fuel treatments.

[21] Principal Investigators: Tanana Chiefs Conference, Inc. Forester Dr. Bob Ott and Alaska Fire Service Fire Ecologist Randi Jandt.
[22] Project initiated by Alaska Fire Service Fuels Management Specialist and UAF student Mark Musitano.

Assumptions and Limitations

1. Non-treatment area represents the treatment area before hand manipulation

2. Variable Plot cruise data assumed to be 100% accurate.

3. All crown mass data was derived using estimates (Barney et. al. 1977.

4. Reduction factor estimates (Barney et. al. 1977) for total available fuel for combustion are accepted as an accurate representation of the available fuel.

5. One of the major limitations in this paper is the lack of a fire behavior modeling process that truly represents the effects of a fuel treatment in terms of fire behavior characteristics. Without the act of an actual field fire experiment in this area, the results of this paper are only theoretical and are limited by the existing models in fire behavior. Custom fuel modeling is one option but not attempted in this project.

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Appendices

Appendix A) Site Location Map
1) Fort Wainwright Hazard Fuel Reduction Projects
2) Fort Wainwright Vegetation Types
3) Shannon Park Fuel Break

Appendix B) Site Photos
1) Aerial View and Fuels
2) Shannon Park Fire Photos
3) Shannon Park Fire Photopoints
4) Treatment Photopoints North Section
5) Treatment photopoints South Section

Appendix C) Fire Intensity and Flame Length Graphs
Figure 1) fire intensity relationship to fuel and rate of spread
Figure 2) intensity relationship to flame length

Appendix D) Critical Fire Intensity Graphs
Figure 3) intensity relationship to live crown base height and foliar moisture content
Figure 4) flame length relationship to foliar moisture content and live crown base height
Figure 5) relationship of rate of spread and crown bulk density

Appendix E) Variable Plot Cruise Data Method Description

Appendix F) Plot Data
1) Non-treatment
2) Treatment

Appendix G) PNW BS10 Photo Series

Appendix H) Fire Behavior Calculations
1) NEXUS
2) FBP 97
   a) Non -treatment
   b) Treatment
3) Behave Moisture Model

Appendix I) Metric Conversion Factors

Appendix J) Canadian Forest Fire Danger Rating System Summary